# MANAGING THE CULTURE OF A COMPLETELY PISCIVOROUS AND VORACIOUS LARVAE, JAPANESE SPANISH MACKEREL *SCOMBEROMORUS NIPHONIUS*: EXPERIMENTAL ESTIMATION OF DAILY FOOD CONSUMPTION

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## ABSTRACT

To establish an appropriate feeding schedule in captivity, feeding rhythm and daily ration of larval Japanese Spanish mackerel *Scomberomorus niphonius* were experimentally estimated and compared to those of wild-caught larvae. Using the model of Elliott and Persson (1978), instantaneous gastric evacuation rates (*R)* were estimated for reared fish (d 8, d 10, and d 15 after hatching) from starvation experiments, and for wild fish (3.0-10.3 mm SL) from the depletion of stomach contents (percent body weight) over time when collected during the night. Japanese Spanish mackerel exhibited piscivorous habits from first feeding and a remarkable peak of feeding activity during the evening, under both laboratory and wild conditions, although primarily a daylight feeder. The estimated value of daily consumption for reared larvae ranged between 90.6 and 111.7% and that of wild larvae was 111.1% of their body weight.

## INTRODUCTION

Japanese Spanish mackerel *Scomberomorus niphonius* is an important fisheries resource distributed throughout southwestern Japan, particularly in the Seto Inland Sea. Total catch exceeded 6000 t in the mid-1980s but it has recently decreased to less than one-twentieth of that amount due primarily to overfishing (Nagai et al. 1996; Kono et al. 1997). It is hoped that the depleted stock can be restored by fishing regulation and seedling release.

To stabilize the catch and establish more effective fisheries management practices, it is necessary to accumulate biological information and understand the recruitment process. Previous biological studies have focused only on the biology of adult fish (Kishida 1986, 1989; Kishida and Aida 1989; Kishida et al. 1985). Recently, information on the early life history of this species has been accumulated and several peculiar ecological features have been clarified: precocious development in the digestive system (Tanaka et al. 1996), piscivorous habits from the first-feeding stage (Shoji et al. 1997), short-term larval occurrence synchronized with peak abundance of prey fish, rapid growth in early life stages (Shoji et al. 1999a), and diel changes in vertical distribution and feeding rhythm (Shoji et al. 1999b).

Japanese Spanish mackerel is anticipated to be an important target for sea-farming because of a high growth potential (reaching 10 mm TL in one month and 600 mm TL in the first growing season: May to November). However, intensive cannibalism during the larval stages has prevented their mass production (Higuchi and Oshima 1974; Fukunaga et al. 1982). Before culture and mass production can be managed effectively, an appropriate feeding schedule must be established.

In this study, using the model of Elliott and Persson (1978), the daily consumption of Japanese Spanish mackerel larvae was estimated based on data obtained from successive 24-h samplings under both laboratory and wild conditions.

## MATERIALS AND METHODS

### Rearing of Fish

Artificial fertilization was carried out with a pair of adult Japanese Spanish mackerel captured by drift gill-net in Harima-nada Sea (the eastern Seto Inland Sea, Japan) in May 1999. Artificially fertilized eggs were transported to Yashima Station, Japan Sea-farming Association (JASFA: Fig. 1), Takamatsu, Kagawa, and maintained in two 0.5 $m^3$ tanks under natural light conditions. Water temperature ranged from 18.2 to 19.5 C during the experiments. Newly-hatched larvae of red sea bream *Pagrus major* were used as the larval feed.

Instantaneous gastric evacuation rates (*R*) for reared fish were estimated from starvation experiments at d 8, d 10, and d 15 after hatching. Because Japanese Spanish mackerel larvae are piscivorous and begin to cannibalize without piscine prey, each 70 or 80 fish were isolated using 2-L plastic cups on the day of the starvation experiments. Ten fish were sampled from each cup at intervals of 30 min to 3 h over a period of 10 h from the beginning of fasting. The stomach content weight index (SCWI) of the sampled fish was calculated as follows: SCWI = 100*dry stomach content weight (SCW) / dry body weight (DBW)

To understand the diel changes in SCWI, a total of 31 samplings were conducted throughout a 24-h period from 0300 on the same day the starvation experiments were conducted. Each 15 to 20 fish used in this determination were removed from the rearing tank every 30 min or 1 h and SCWI was calculated as described previously.

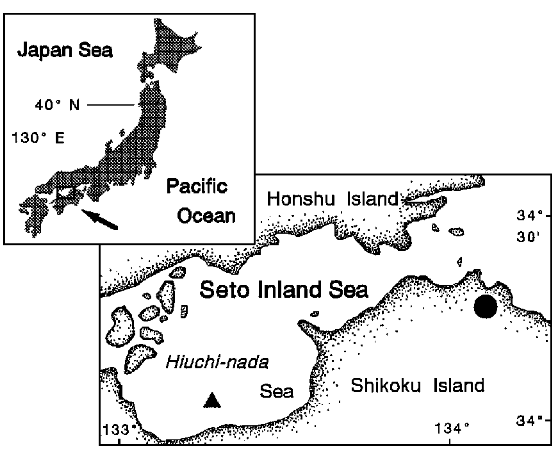


**Figure 1**. Map of the central waters of the Seto Inland Sea showing the JASFA Yashima Station (closed circle) where rearing experiments were conducted May to June 1999 and a sampling station (triangle) where Japanese Spanish mackerel larvae were collected over a 24-h period on 3-4 June 1997.

### Field Sampling

A 24-h survey was carried out during a cruise on the R/V *Hiuchi* (Ehime Prefecture, Chuyo Fisheries Experimental Station) in the Hiuchi-nada Sea, central Seto Inland Sea (Fig. 1). A total of 10 sets of larva-net tows were conducted at intervals of about 2 h from 1033 on 3 June 1997. Details of the sampling method are described in Shoji et al. (1999b). The stomach contents of 209 larvae, ranging between 3.0 and 10.3 mm SL, were examined and SCWI was calculated.

### Estimation of Gastric Evacuation Rate (R) and Daily Ration

The daily ration of Japanese Spanish mackerel was estimated in terms of percent body weight using the model from Elliott and Persson (1978):

$$C_t=(S_t-S_0e^{-Rt})Rt/(1-e^{-Rt})$$

where the $(C_t)$ is the consumption of food during the time interval from $t_0$ to $t_1$ observed from the average amount of food in the stomach expressed as stomach, content weight index (SCWI) at time $t_0$ $(S_0)$, the average stomach content index at time $t_t$ $(S_t)$, and the instantaneous evacuation rate $(R)$. The estimates of $C_t$ calculated for each time interval are then summed to give the total daily ration.

The value *R* for reared fish was estimated from the reduction of SCWI during the starvation experiments using the following equation:

$$R=(1/t)\ln(S_0/S_t)$$

The SCWI of wild-caught Japanese Spanish mackerel larvae was high during the daytime and declined during the night while the percentage of those with empty stomachs increased after sunset (see Results: Fig. 6). Therefore, assuming no feeding between sunset and sunrise, *R* for the larvae was estimated from the reduction of SCWI during the night. Evacuation rate is therefore given by

$$S_{sr}=S_{ss}e^{-Rt'}$$

which, in its logarithmic form, is

$$\ln(S_{sr})=\ln(S_{ss})-Rt'$$

therefore,

$$R=(1/t')\ln(S_{ss}/S_{sr})$$

where the instantaneous evacuation rate (*R*) is calculated from the average SCWI of the sample collected at sunset $t_{ss}$ ($S_{ss}$), the average SCWI at sunrise $t_{sr}$ ($S_{sr}$), and the time interval between $t_{ss}$ and $t_{sr}$ ($t'$).

# RESULTS

## Estimation of Gastric Evacuation Rate (R) and Daily Ration for Japanese Spanish Mackerel Larvae Under Rearing Conditions

Japanese Spanish mackerel larvae initiated feeding on d 5 after hatching. Mean sizes of fish sampled for the experiments at d 8, d 10, and d 15 after hatching were 6.84, 8.72, and 12.11 mm SL, respectively (Fig. 2). In the starvation experiments, *R* was derived from the set of SCWI values during 10 h since the onset of fasting, which were plotted in the exponential equation (Fig. 3). The values of *R* obtained from these data of fish at d 8, d 10, and d 15 after hatching were 0.282, 0.324, and 0.311, respectively.

Diel changes in SCWI of Japanese Spanish mackerel larvae increased after dawn until evening and decreased throughout the night ( Fig. 4). The SCWI and the *R* were used to estimate the food consumption for each time interval ($C_t$). A few of the estimated values of food consumption per hour ($C_t/t$) for fish at d 8 and d 15 after hatching appeared to be negative in captivity. Durbin et al. (1983) considered that the negative values were caused when the decline in

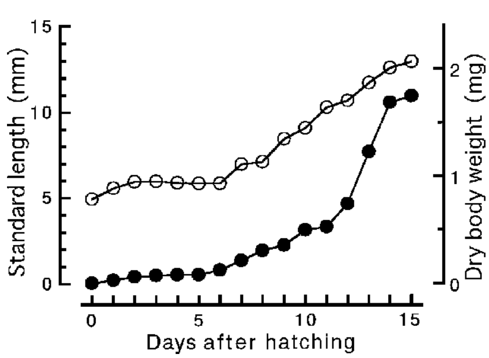


**Figure 2.** Mean standard length (open circle) and dry body weight (closed circle) of Japanese Spanish mackerel larvae reared at JASFA Yashima Station in 1999. The larvae initiated feeding on d 5 after hatching.

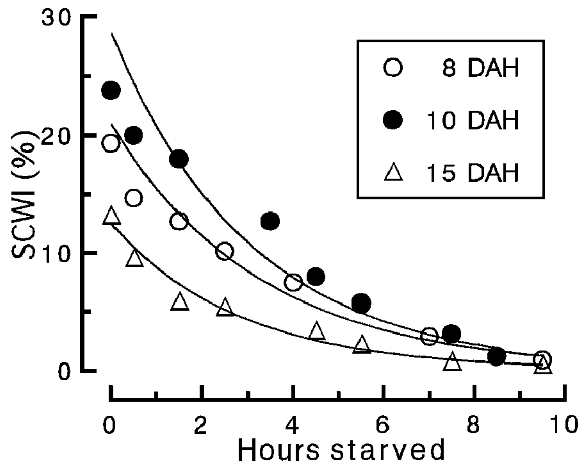


**Figure 3.** Changes in stomach contents weight indexes (SCWI) during the starvation experiments of Japanese Spanish mackerel larvae at d 8, d 10, and d 15 after hatching. Each reduction of SCWI was used for estimating the gastric evacuation rate (see text). Estimated *R*s for fish at d 8, d 10, and d 15 after hatching were 0.282, 0.324, and 0.311, respectively.

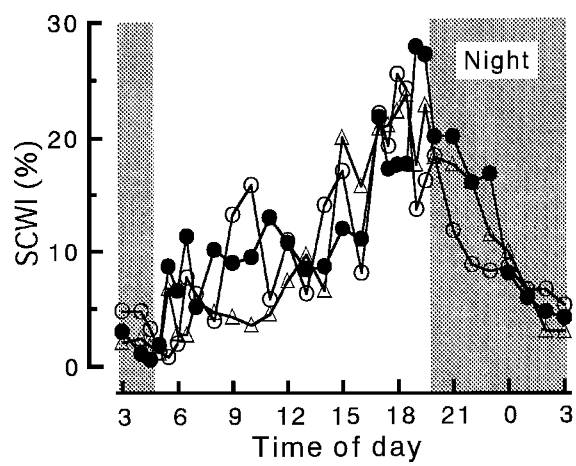


**Figure 4.** Diel changes in stomach contents weight index (SCWI) of the reared Japanese Spanish mackerel larvae at d 8, 10, and 15 after hatching. Legends same as in Fig. 3.

the amount of food in the stomach from one period to the next was greater than predicted from the evacuation rate used in the calculation, and they summed the amount of food ingested during each period, including the negative values, to obtain the daily ration. In this study, daily ration was determined by summing both positive and negative values. Daily ration of fish at d 8, d 10, and d 15 after hatching reached 104.9, 111.7, and 90.6% of body weight, respectively (Fig. 5).

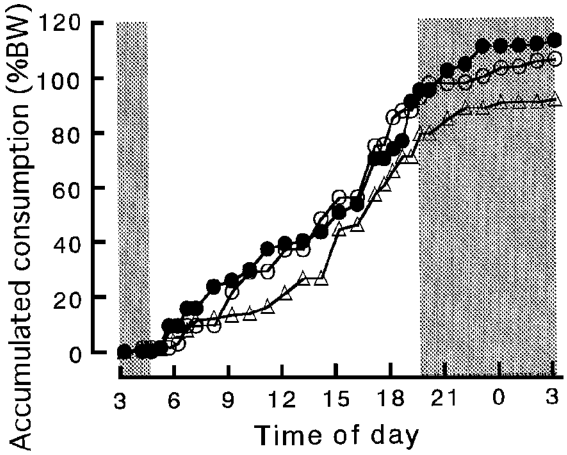


**Figure 5.** Diel changes in accumulated values of food consumption (% BW) for reared Japanese Spanish mackerel larvae at d 8, d 10, and d 15 after hatching. Elliott and Persson's method was applied to estimate the values of food consumption. Using the gastric evacuation rate of 0.282 (8 DAH), 0.324 (10 DAH), and 0.311 (15 DAH), accumulated values of food consumption were calculated as 104.9, 111.7, and 90.6% of body weight, respectively. Legends same as in Fig. 3.

## Estimation of Gastric Evacuation Rate (R) and Daily Ration for Japanese Spanish Mackerel Larvae Under Wild Conditions

Stomach contents of the wild-caught Japanese Spanish mackerel larvae consisted exclusively of other fish larvae (Shoji et al. 1999b). Diel changes in the percentage of fish with empty stomachs and SCWI were observed (Fig. 6) and the percentage of fish with empty stomachs increased during the night and reached a maximum at dawn. SCWI reached a maximum at dusk, then consistently decreased during the night to a minimum at dawn. This reduction of SCWI during the night was plotted in the exponential equation and the gastric evacuation rate (*R*) for

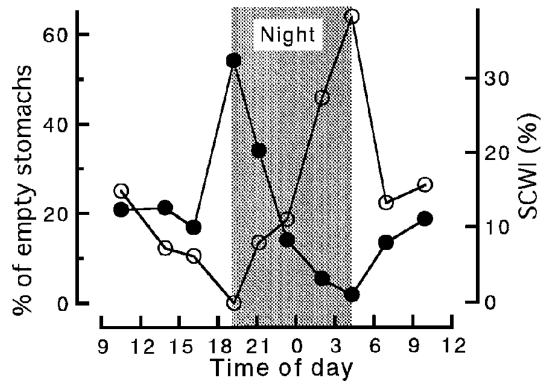


**Figure 6.** Diel changes in percentage of empty stomachs (open circle) and stomach content weight index (SCWI: closed circle) of Japanese Spanish mackerel larvae collected during the 24-h sampling in the central Seto Inland Sea on 3-4 June 1997. Using the reduction of SCWI during the night when the larvae were considered not to feed, gastric evacuation rate of wild larvae (0.338: see text) was estimated.

the wild-caught larvae was estimated as 0.338. The SCWI and *R* were used to estimate the food consumption for each time interval. Daily ration for wild-caught larvae reached 127.2% of body weight (Fig. 7).

# DISCUSSION

## Comparison of Daily Rations Among Scombrid Larvae

Daily ration of Japanese Spanish mackerel larvae was estimated as 127.2 % of BW

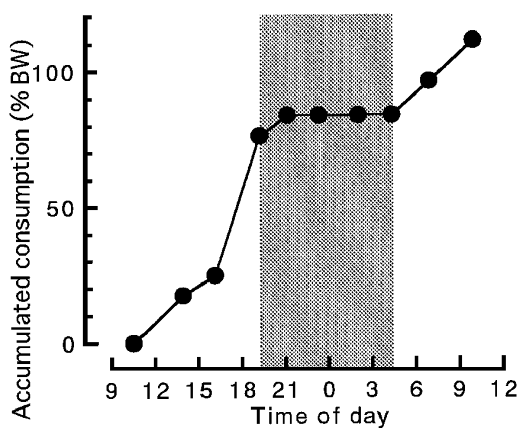


**Figure 7.** Diel changes in accumulated food consumption for Japanese Spanish mackerel larvae collected during the 24-h sampling in the central Seto Inland Sea on 3-4 June 1997. Elliott and Persson's (1978) method was applied to estimate the values of food consumption. Using the gastric evacuation rate of 0.338, daily ration was calculated as 127.21% of body weight.

for fish in the wild and between 90.6 and 111.7 % for fish in captivity. From these values it is reasonable to characterize the feeding behavior of Japanese Spanish mackerel larvae as voracious. Lower values of daily ration for other scombrid larvae, Atlantic mackerel *Scomber scombrus* (Peterson and Ausubel 1984), southern bluefin tuna *Thunnus maccoyii*, and albacore tuna *Thunnus alalunga* (Young and Davis 1990) have reportedly been 25 and 50% of BW. Hunter and Kimbrell (1980) reported a higher value (87%) for Pacific mackerel *Scomber japonicus* larvae under culture conditions.

Voracious habits exhibited in this study might account for the high growth potential of Japanese Spanish mackerel larvae. Mean gross growth efficiency (percentage of increase in BW to weight of accumulated food consumption) of Japanese Spanish mackerel from first-feeding stage until d 15 after hatching under rearing and wild conditions were calculated as 33 and 26%, respectively. Hunter and Kimbrell (1980) reported mean growth efficiency of 33% for Pacific mackerel larvae under culture conditions. Compared with other scombrids such as Atlantic mackerel (Kendall and Gordon 1981), southern bluefin tuna (Jenkins and Davis 1990), bluefin tuna (Scott et al. 1993), and yellowfin tuna *Thunnus albacares* (Lang et al. 1994), which are planktivorous during their early larval stages, Japanese Spanish mackerel exhibits a higher growth rate (approximately 1.0 mm/d) (Shoji et al. 1999a) during the larval and early juvenile stages. The faster growth can be attributed to the unique feeding habits of Japanese Spanish mackerel larvae: piscivorous from first-feeding larval stage (Shoji et al. 1997). In addition, the histological observations of Tanaka et al. (1996) described a functional digestive system of reared Japanese Spanish mackerel larvae at the first-feeding larval stage: a large expanded blind-sac with consumed fish larvae. The precocious development of the digestive system could account for the voracious and piscivorous habits and high growth potential from the first-feeding larval stage.

### Implication for Stock-enhancement of Japanese Spanish Mackerel

Japanese Spanish mackerel are a commercially important fisheries resource and recovery of the depleted stock in the Seto Inland Sea is critical. Because of the unique and fierce feeding habits of Japanese Spanish mackerel, however, particular attention should be given to possible influences which might be caused by the mass release of seed or sudden increase in biomass of the target species upon other related species. Japanese anchovy *Engraulis japonica*, an important prey for larval and adult Japanese Spanish mackerel (Kishida 1986; Shoji et al. 1997), would suffer from more intensive predation by an increase in biomass of Japanese Spanish mackerel. In addition, several species of young and adult piscivorous fish, such as chub mackerel and ribbon fish *Trichiurus leptulus* (Hashimoto et al. 1989), might face interspecific competition with Japanese Spanish mackerel. Recently, techniques for the mass culture of Japanese Spanish mackerel have been established in Japan. To reduce any potential negative impacts upon other species by the stock-enhancement activities of Japanese Spanish mackerel, monitoring the availability of prey species, their distribution and abundance in the sea is imperative.

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